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PUMPING MACHINERY

TEST DUTY VS. OPERATING RESULTS

By J. N. Chester

This paper is the result of an effort prompted by a request from our Secretary starting with the statement that "we now install pumping engines of 200,000,000 foot pounds guaranteed duty, but get much less every day efficiency," and ending with the admonition that we "dwell on what the coal piles should give us in water pumped."

History relates that over 2000 years ago, one Alexander the Great wept because there were no more worlds to conquer. This being the case, we are quite sure that Alec up to that time at least, had never looked into the possibilities of steam plant efficiency.

From physics we learn that heat and energy, or work, are equivalent and mutually convertible one to the other. Our pump station results represent work. The source of the heat to perform this work is coal, and the means for converting the heat of the coal into work is our steam plant equipment. The per cent of the heat contained in the coal that may be realized in useful work or energy, represented by the water delivered into our mains, and why the losses is the problem before us.

The coal we buy contains, we will say, 100 per cent of heat, not that coals do not differ in heat producing or thermal values, but let us assume that the coal we have contains heat represented by 100 per cent, then to those familiar with the subject, it is well known that with the contrivances in use to this date, we have been able to make apparent in work done as represented by the water column delivered with the most efficient machines, less than 20 per cent of the 100 per cent of heat in the coal fired under our boilers and in many instances, the net result does not exceed 5 per cent. Why this loss?

In the boilers, due to the heat that must necessarily pass out through the stack so that the temperatures of the hot gases in the boilers may be in excess of the temperature of the steam generated and thus effective throughout their entire travel through the boiler, coupled with the radiation of the exterior parts of the boiler and the incomplete combustion of fuel represented by the combustible matter remaining in the ash, test boiler efficiencies are not obtained greatly in excess of 70 per cent, or otherwise stated, we realize only in net heat delivered as dry steam from the boiler, 70 per cent of the total heat contained in the coal, which we termed 100 per cent.

Next comes the steam lines and be they long or short, properly or poorly proportioned, bare or well covered, some radiation must take place, and some loss due to friction must be further incurred, for friction represents energy and energy is heat and so, under the best of conditions, we can expect to deliver less than 70 per cent of heat of the coal converted into steam and less than 70 per cent at the engine throttle.

Then due to the ineffective utilization of the heat delivered at the throttle by the highest grade steam motors or engines in use today, which seldom exceeds 20 per cent, we find the net results left of our original 100 per cent in the coal approximately 15 per cent.

As a concrete illustration of the above, recent final and preliminary duty and efficiency tests at Erie, Pennsylvania, showed that of the available heat units determined by analysis of the coal fired, the boilers delivered at their outlet nozzles 71 per cent, and of the available heat units received by the steam pipe at the discharge nozzle of the boilers it delivered to the throttle at the engine 99.6 per cent; and that the engine converted into useful work but 21.5 per cent of the available heat units delivered at its throttle by the steam pipe, or that the entire combination, not considering auxiliaries of any sort, showed an overall efficiency of 15.25 per cent, and still the engine on preliminary test (final test not yet run) performed a duty of 205,348,000 foot pounds for each 1000 pounds of steam consumed.

But probably, to be more readily understood by the water works operator, we would better restate this problem in the terms of the relations between test duties based on 1000 pounds of dry steam and obtained on tests for acceptance as compared with every day operating results per 100 pounds of coal fired under the boilers.

Before getting too deeply in either discussion, let it be known that we have accorded the field of plants consuming one million and less to the internal combustion engine and electric motor driven pump.

For pumping units on which the demand is 1,000,000 gallons or more daily, practical test duties vary from 50,000,000 to 200,000,000 foot pounds of useful work performed for each 1000 pounds of dry steam delivered to such unit.

For the same machines, the station duty would be expected to vary from 20,000,000 to 125,000,000 foot pounds of work done for each 100 pounds of coal fired under the boilers.

Why the difference between the maximum steam duty of 200,000,000 and the coal duty of 125,000,000? Also the minimum steam duty of 50,000,000 and the minimum coal duty of 20,000,000?

Pump station results, as most of us know, are affected by the following:

1. Quality of coal.
2. Efficiency of boilers.
3. Efficiency of steam lines.
4. Station capacity.
5. Head against which water is delivered.
6. Load factor.
7. Adaptability of machinery.
8. Compactness of station.
9. Low vacuum in condensing units.
10. Care in operation and many other minor elements.

For easy handling, let us take the case of a station in which the major unit is capable, when in service, of pumping all the water demanded and whose test duty was one hundred million foot pounds per 1000 pounds of dry steam delivered to it, and endeavor to make clear the differences between steam and coal duty.

Naturally, if each pound of coal fired under the boiler would evaporate into steam, at the pressure desired, ten pounds of water and none of this steam became condensed in the channels conveying it to the engine, then there would be no difference between coal duty and steam duty. Unfortunately, this is not the case.

In the average water works station with the best coal, Pennsylvania or West Virginia product, we are able to obtain but an average of about 8 pounds of water evaporated per pound of coal burned. Consequently, if nothing more than this existed, our steam duty of 100,000,000 would be reduced to 80,000,000 in station duty. Besides, we cannot all locate our stations within a practical shipping distance from the Pennslyvania or West Virginia coal fields, and those who obtain their coal from the Ohio districts must expect about 7 pounds of water per pound of coal, and from the Illinois and Indiana districts, in the neighborhood of 6 pounds of water per pound of coal, so that the latter has reduced the 100,000,000 duty to 60,000,000 duty without further inroads. So much for the quality of coal.

The above evaporative results are based on the ordinary boiler efficiency of about 65 per cent, which calls for intelligent firing, the boiler operating, within at least 80 per cent of its rated capacity, grates that will prevent there remaining in the ash more than 5 per cent combustible, a stack draft that will supply the coal being consumed with the necessary amount of air, boiler walls sufficiently tight to prevent the admission of air above and beyond the grates in quantities that will interfere with the best combustion, and the whole exterior of such a construction as to provide an insulation that will keep down the loss of heat by radiation to the minimum.

Unfortunately, the above are seldom found in the ordinary small water works plant in a combination that provides a boiler efficiency greatly in excess of 50 per cent, and efficiencies running as low as 40 per cent are frequently found, so in the latter case, even when firing a coal from which a high evaporation might be expected, a much lower net result is obtained.

Much more may depend upon whether the steam lines are well proportioned, for if too large and the velocity sluggish, the condensation will be increased. If too small, a portion of the heat must be lost in friction. If bare, a large amount of useful energy escapes through radiation, and in 90 per cent of our steam plants the covering has been done to no specifications other than the will of the company manufacturing and installing such commodities, wherein the covering generally stops short of flanges or fittings about 2 inches on each side, seldom fits the pipe tight, and in consequence, is but 50 per cent as efficient as though it were continuous over fittings and provided against air circulating between the covering and the steam pipe. A 10 per cent loss of energy between boilers and engines is not an uncommon one, when by proper care in design and construction it can be kept within 1 per cent.

The next great loss comes from a source which has been frequently referred to in the meetings of this association, and while many of the pump and boiler builders think it is a hobby, yet you may be assured it exists in 90 per cent of our plants in stern reality. It is the varying demand and head and consequent load factor of the plant, and it is not a matter that either the designing engineer or the operating officials can correct. Metering intensifies it, so even when brought to the minimum, it still remains a large factor, causing inroads on economy; for though the water may be pumped once and then to a reservoir, a well selected engine should, at the time it is purchased, exceed in capacity the demands to be made upon it, and although when operated the reservoir may permit it to deliver at its rated capacity while in operation and thus the maximum of economy from this standpoint obtained, it must, a portion of its time, be either shut down or operated below rated capacity, and so subject its economical possibilities to the inroads of the fixed thermal charges that continue whether the pump is in operation at full or half speed.

With 75 per cent of our water works plants there exists no high level reservoir and, consequently, the delivery of the pump is governed by the demand on the mains, which varies throughout the twenty-four hours in the ratio of its extremes of about one to three.

Then again, in many plants having a capacity of less than 10,000,000 gallons daily, fire service is rendered by direct pressure, which calls for an increase when the alarm comes in of from twenty to sometimes 100 per cent, for all of which the boiler power must be kept in constant readiness, thus increasing grossly the fixed thermal losses necessarily to be charged against the station's efficiency.

When an engine is tested for acceptance and to prove the builder's guarantee of efficiency, we unfortunately too often set up in the purchaser's mind a standard which he hopes to but never in the future realizes, not only for the reasons above discussed, but others to follow, one of which is that during this duty test, we simply measure the steam used by the engine, neglecting, of course, that used by many of the auxiliaries such as the feed pump, the electric light engine now to be found in a majority of stations, sometimes the blowing engine that produces the draft, and frequently the air compressor that charges the chambers, the heating of the station and frequently adjacent buildings, all of which may represent a draft on the boilers from ten to 100 per cent of that of the main engine.

As an example of the above, extracts from an analysis made by a university professor and his class of a pumping plant in Pennsylvania where one pump in operation did all the work and was ordinarily run at full capacity, the following distribution of steam generated was ascertained:

	Per cent
Consumed by main engine	60.45
Consumed by air pump	16.20
Consumed by lighting unit	4.20
Consumed by Holley vent to atmosphere	6.62
Consumed by drains, heating coils, etc	5.47
Consumed by Holley return and engine jackets	7.06
Total	100.00

The boilers were fed from the pressure in the discharge mains.

The writer, some years ago, during an engine test at Jamestown, New York, measured the water into the boilers and from the discharge of the air pump of the main engine which, aside from the feed pump in the boiler room, and a steam jet employed to eject the condensate from the dry well was the only steam consuming element in operation other than that steam was being supplied to the jackets of two idle engines in order to keep the station warm, the temperature outside being sixteen below zero, and the final results showed the water discharged from the air pump and jackets from the main engine was but a trifle over 50 per cent of the total fed during the period of the test to the boilers.

In recent years, due to our constantly increasing population and consequent congested districts with modern sanitary methods, the majority of our water supplies, to be safe, must be filtered, and the installation of purification plants unfortunately generally necessitates the water being pumped from the source to the filters and again repumped to the mains whence the consumption is drawn. Notwithstanding this, that individual, to whom the man immediately responsible for the economy of this station must report, forgets this fact and is prone to demand, as a station duty, the test duty of but what may be termed the high service unit, ignoring all of the elements enumerated above and which must necessarily make inroads on the station's efficiency.

There is too great a tendency on the part of the station or operating engineer to neglect or disregard his means for removing the back pressure from the exhaust side of the low pressure piston in his engines, otherwise known as his condenser and air pump or vacuum producing facilities, for with even reciprocating engines, nothing less than 26 inches, as indicated by the mercury column, should be tolerated, while unexpected visits generally find in the neighborhood of 20 inches.

The loss due to low vacuum may be roughly reckoned in reciprocating engines at 1 per cent for each inch of mercury. Steam turbines require, for economical operation, a much greater vacuum than 26, and while the condensing facilities may be nursed at the time of the test to produce the desired results, the greater is the fall when the lower vacuum of every day results becomes effective.

Taking up the last of the major elements that tend to reduce plant efficiency, we come to what is too frequently found, to wit: the inadaptability of many of the steam producing, pumping and auxiliary units due many times, to be sure, to changes that have taken place that are beyond the control of those responsible for their presence, but often, to the exercise of bad judgment, or none at all, in their original selection and installation, arising mainly from an unwillingness to incur expense of expert advice in the selection of same and a proneness to permit manufacturers to make the final recommendation.

This reference to manufacturers must not be construed by them as too great a reflection upon their ability to act in such capacity, but from the writer's own experience which reoccurs nearly every time a new station is to be built or an old one to be rebuilt, when, first, the individual with electric current to sell appears, and many times accompanied by another with an electrically driven pump to dispose of, and endeavors to convince him that electrically driven pumping machinery, regardless of conditions of service, is the only kind that will properly meet the situation; then comes the steam turbine driven centrifugal advocate followed naturally by the builders of the several different types of reciprocating machinery, all of whom thoroughly believe and earnestly insist that what they have to offer is what the conditions at hand demand, and only a simpering idiot would select anything else, and so the individual, whose experience is limited to the operation of but one plant, too frequently falls a victim to the wiles of the overzealous and inconsistent salesman.

To conclude this paper with something tangible as a representation of the general conclusions of what we have hereinbefore discussed, the writer has prepared diagrams which at least, in a general way, indicate what, under certain circumstances, we have reasons to expect.

In figure 1, is plotted graphically the cost of energy to pump

1,000,000 gallons of water both by steam and electricity against 100 pounds gross head with electrical machines having efficiencies varying from 30 to 80 per cent current costing $0.1 per K.W. hour and with steam machines producing a station duty varying from 20,000,000 to 200,000,000 foot pounds duty per 100 pounds coal burned under the boilers and with coal at one dollar per ton, and from this diagram, those interested may readily obtain the energy cost at any efficiency of electrical unit, or duty of steam unit, and at any cost of current or coal by one simple multiplication, and in using this diagram, don't be too optimistic regarding either efficiency or duty.

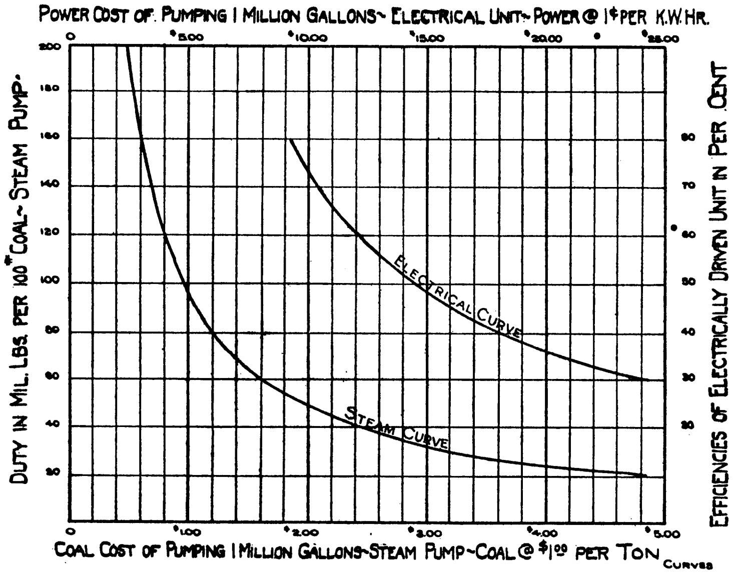

FIG. 1

CURVES
showing
COST OF PUMPING WATER
against a
PRESSURE OF 100 LBS. PER SQUARE INCH

Figure 2 is of the same nature as figure 1, except that it is so prepared as to be more applicable to low service or filter pump work, the head being assumed at 50 feet instead of 100 pounds as in figure 1.

The diagrams represent actual results that may be obtained under the conditions given and their intelligent use may prevent water works operators from being lured into the use of electricity under

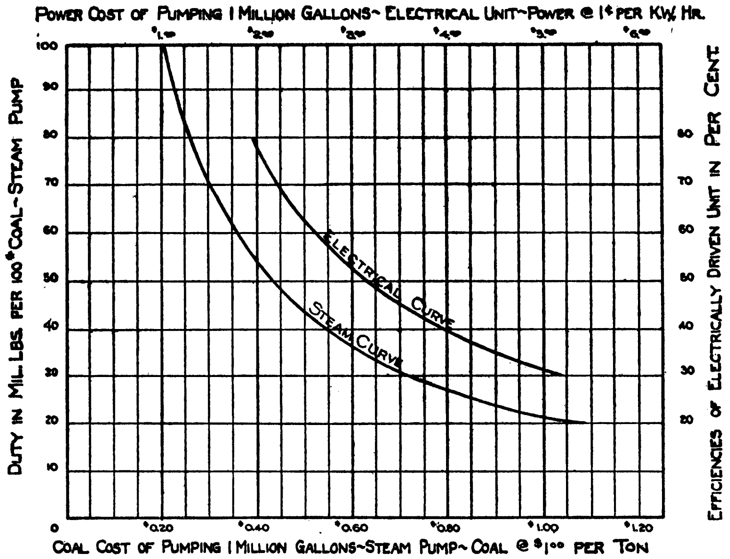

FIG. 2

CURVES
showing
COST OF PUMPING WATER
against a
HEAD OF 50 FEET

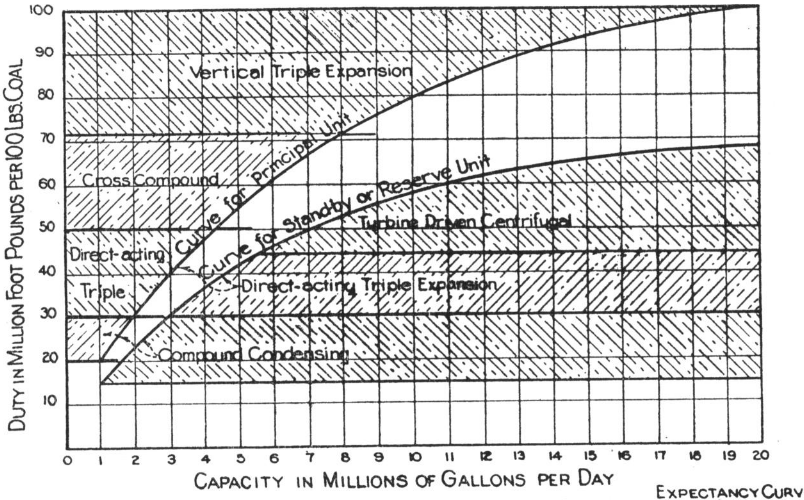

FIG. 3

EXPECTANCY CURVES
for
PUMPING ENGINES
working against a
PRESSURE OF 100 LBS

false apprehensions and even though at first glance the results look attractive, the operator must not forget that the underwriters' requirements are yet to be reckoned with.

Figure 3, attempts to represent graphically the writer's ideas, under general conditions, of the machines that should be selected for certain capacities for both principal engine and alternate and the station duty they may be expected to produce, but you must realize that this intends the principal engine doing at least 90 per cent of the work and that the head, the cost of coal, the load factor, the cost of real estate in the construction of new plants or additions to old ones, and where the machine must be installed in existing stations, the boiler pressure and space available, and finally, in both cases, the funds available, are factors which may shift both the horizontal and the curved lines.

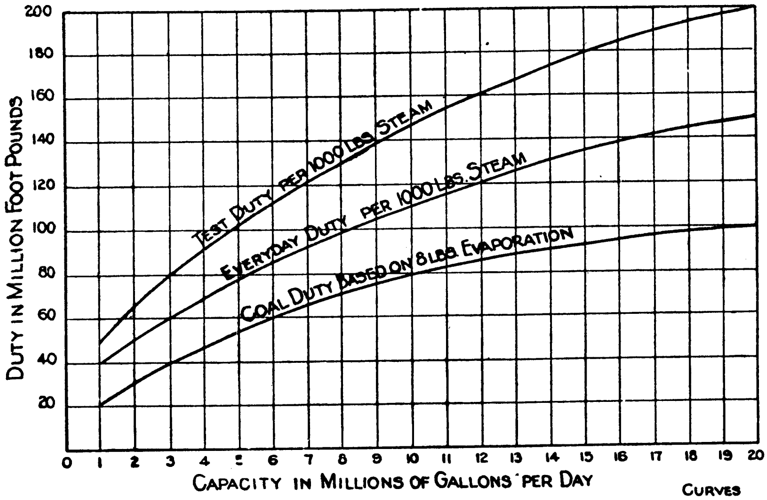

FIG. 4

Curves
showing relations between
Test and Operating Duties
on
Steam Pumping Engines

Figure 4 is extending this same idea, and in this chart it has been attempted to plot both the test or steam duty, and the every day station or coal duty of the No. 1, or main engine.

The turbine driven centrifugal advocate will probably not feel complimented by the failure to get his machine in the No. 1 line, and this table must only be construed as portraying that under the conditions assumed, it is not most applicable as No. 1 and not that conditions might arise where it would be more applicable than the reciprocating machine even as No. 1.

The steam turbine, as a power producer, has made in the past five years more rapid strides in economy than any other type of steam motor, and many of us will live to see it almost entirely supplant the reciprocating engine.

For the purpose of driving electric generators above 500 K.W. capacity, it holds the field alone, but as a driver of large pumps, there must necessarily intervene, for best results as to economy, gears which are objectionable both from the standpoint of their noise and their upkeep. In small units, the high vacuum necessary to produce the economy which steam turbine builders claim is difficult to produce and seldom forthcoming after the duty test is made.

In the field of filter or low service pumps of ten million capacity or over, the centrifugal pump reigns supreme, and for constant low heads of 20,000,000 capacity or over the turbine driven centrifugal usurps the field.

The curves above presented and the opinions they delineate are for the state of the art as of today. That there has been frequent shifting of these lines in the past five years argues that they will further shift in the future. During the period of low prices just past, the cross compound for a time almost wholly usurped the field of the direct acting triple, and with the rapid strides that the turbine driven centrifugal has made, as above predicted, its field will rapidly enlarge and the first machine that the writer expects it to crowd wholly from the map is the vertical triple expansion crank and fly wheel.